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Optimization and management of the energy produced by a wind energizing system

Wissem Zghal*, Gueorgui Kantchev, Hédi Kchaou

Laboratory of Electromechanical Systems, National Engineering School of Sfax, B.P. W3038, Sfax, Tunisia

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A B S T R A C T

The present paper presents a new method for sizing and techno-economical optimization of an autonomous wind system. The main objective of the present study is to find the optimum size of system, able to accomplish the energy requirements of a given load distribution, for a specific site, and to analyze the impact of different parameters on the system size.

Modeling of the autonomous wind system is considered as the first step in the optimal sizing procedure. In this paper, more accurate mathematical models for characterizing the main subsystems (wind generator and unit of storage) are proposed. Based on lack of energy to generate probability (LEGP), percentage of the surplus of energy produced (PSEP) and the cost of the kilowatt-hour produced (C_{kWh}), the second step consists in optimizing the sizing of a system.

A simulation software code has been developed to carry out the analysis for optimizing the size of the system. Also, a case study using the software code has been presented to determine the optimal system configuration used to satisfy the requirements of a typical residential home (5 kWh/day) located in Sfax, Tunisia.

Contents

1. Introduction

Global environmental concerns, the important increasing need for energy and the rapid depletion of fossil fuel resources on a worldwide basis have necessitated an urgent search for alternative energy sources to supply the present day demands. The stable progress in renewable energy technologies is opening up new opportunities for the use of renewable energy resources.

However, solar and wind energy systems are being considered as promising power generating sources due to their availability and the topological advantages in local power generation.

To use these energy resources more efficiently and economically, the optimal sizing of renewable energy system plays an important role in this respect. Various optimization techniques of these systems sizing have been reported in the literature such as the probabilistic strategies or approach [1–3], graphical

* Corresponding author. Tel.: +216 97750882.
E-mail address: zghal_wissem@yahoo.fr (W. Zghal).

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Nomenclature

a	actualization factor
B_j	daily energizing need (kWh)
C_B	batteries capacity (Ah)
C_e	efficiency coefficient of the wind turbine
C_{ii}	initial cost of investment (€)
C_{kWh}	cost of the kilowatt-hour produced (€)
C_m	maintenance cost (€)
C_p	power coefficient
C_r	replacement cost (€)
C_{ta}	actualized total cost of the project (€)
E_B	energy available in the unit of storage (kWh)
$E_{B_{max}}$	maximum allowable storage energy (kWh)
$E_{B_{min}}$	minimum allowable storage energy (kWh)
E_e	total produced energy (kWh)
E_{ea}	quantity of energy produced per year (kWh)
f_m	annual expansion factor
f_r	replacement factor
LEG	lack of energy to generate (kWh)
LEGP	lack of energy to generate probability
n	system lifetime
N	number of consumer appliances
nb	batteries lifetime
N_{ja}	number of autonomy days
P_{an}	nominal power of receiving device (W)
P_D	maximal depth of discharge
P_e	recoverable wind power (W)
P_g	nominal power of the generator (W)
P_m	power to the exit of the multiplier (W)
P_n	nominal power of the wind turbine (W)
PSEP	surplus of energy produced percentage
P_t	transmitted power (W)
P_v	wind power (W)
r	actualization rate
R	blade radius (m)
R_T	correction factor of the temperature
S	blade swept area (m^2)
SEP	surplus of the energy produced (kWh)
t_j	number of hour of utilization in day
V	wind velocity (m/s)
V_B	voltage for the unit of storage (V)
V_{ref}	wind speed at the reference height (m/s)
Z_{ref}	reference height (m)

Greek letters

α	ground surface friction coefficient
β	pitch angle
η_{bat}	batteries efficiency
η_g	output of the generator
η_m	output of the multiplier
η_{ond}	inverter efficiency
λ	tip speed-ratio
π_g	efficiency factor of the generator
π_m	efficiency factor of the multiplier
ρ	air density (kg/m^3)
σ	self-discharge rate
Ω	various rotation speeds (rad/s)

or energetic construction method [4–6] and iterative technique [7–14].

Tina et al. [1] presented a probabilistic approach based on the convolution technique to incorporate the fluctuating nature of the resources and the load, thus eliminating the need for time-series data, to assess the long-term performance of a hybrid solar-wind system for both stand-alone and grid-connected applications.

Through the paper of Delarue [4], an energetic macroscopic representation is used to describe wind conversion systems composed of very different parts. This representation yields the simulation model of the overall system based on energetic considerations. Moreover, a control structure can be deduced from this representation by simple inversion rules.

Yang et al. [7,8] has proposed an iterative optimization technique following the loss of power supply probability (LPSP) model for a hybrid solar-wind system. The number selection of the *PV* module, wind turbine and battery ensures the load demand according to the power reliability requirement, and the system cost is minimized.

Besides, some authors follow other methods, which are based on the theoretical and experimental study on the aerodynamic characteristics of a wind turbine, to determine the optimal sizing of the wind system. For example, development of a small domestic wind turbine is the main objective of the study of Wang et al. [15,16]. So a modeling studies on a number of key design parameters of the turbine aerodynamics, which is outlined as follows: BEM theory was employed to design the new blades, and the rotor design was optimized by the CFD methods. Also, Kishinami et al. [17] demonstrated in these works the aerodynamic performance characteristics of the horizontal axis wind turbine in two stages: theoretically by the combination analysis involving momentum, energy and blade element theory by means of the strip element method, and experimentally by the use of a subscale model.

A common disadvantage of the optimization methods described above is that they still have not found the best compromise point between system power reliability and system cost. Also, these sizing methodologies do not take into account some system design characteristics, such as wind turbine installation height, regulation system of blade angle of wind turbine that also highly affect the resulting energy production and system installation cost.

In this paper, a new method for optimization of autonomous wind systems for a specific location has been developed based on the lack of energy to generate probability (LEGP), percentage of the surplus of energy produced (PSEP) and the cost of the kilowatt-hour produced (C_{kWh}). The optimization procedure aims to find the configuration that yields the best compromise between the three considered objectives: LEGP, PSEP and C_{kWh}. A simulation software code has been developed to carry out the analysis for optimizing the size of the stand-alone wind system.

2. Wind energizing system presentation

To be able to transform the wind energy in electricity and to exploit it, it is necessary to arrange an energizing system that assures the conversion of energy, the storage and the control of the produced energy. A wind power generation system is made up of wind turbine, unit of storage (generally battery bank), command system that assures the control of the different components and other accessory devices and cables. A schematic diagram of the basic wind system is shown in Fig. 1.

When the energy source (wind energy) is abundant, the generated power, after satisfying the load demand, will be supplied to feed the battery until it is full charged. On the contrary, when the energy source is poor, the battery bank will release energy to assist the wind turbine to cover the load requirements.

In this paper, one concentrates to wind systems that use horizontal axis wind turbine. In order to predict the wind system performance, the different components need to be modeled.

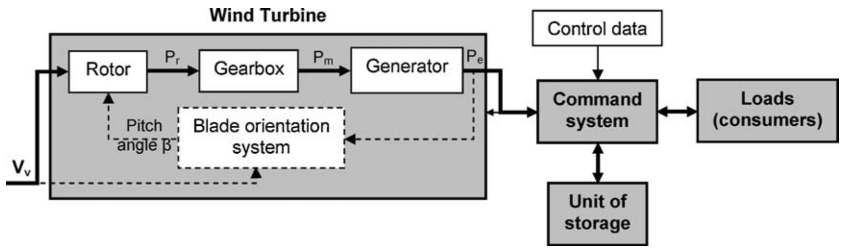

Fig. 1. Schematic diagram of wind system.

3. Modeling of an autonomous wind energy conversion system

Various modeling techniques are developed by researchers to model wind system components. For an autonomous wind system, two main subsystems are included, the wind turbine and the unit of storage. General methodology for wind system components modeling is explained below.

Indeed, the optimum sizing of an energizing wind system starts with an assessment of the user's daily consumption. This assessment is the most important factor for the system components characteristic calculation.

To determine the consumer's total consumption, it's necessary to calculate the daily energizing need B_j that can be represented as follows:

$$B_\mathrm{j} = \sum_{i=1}^{N}(P_{\mathrm{an}_i} t_{\mathrm{j}_i}) \quad (1)$$

3.1. Mathematical model of wind generator

Choosing a suitable model is very important for wind turbine power simulations. There are three main factors that determine the power output of a wind turbine: the wind speed distribution of a selected site where the wind turbine is installed, the power output curve of a chosen wind turbine (determined by aerodynamic power efficiency, mechanical transmission and converting electricity efficiency) and the tower height.

As it is presented in Fig. 1, the wind turbine is considered organized by three main elements that are the rotor, the gearbox (multiplier) and the generator.

In this paragraph, the mathematical models of these elements are presented to finally determine the quantity of energy that can be produced by a wind turbine.

The wind power acting on the blade swept area S is a function of the air density ρ and the wind velocity V:

$$P_\nu = \tfrac{1}{2}\rho S V^3. \quad (2)$$

However, this power cannot be totally recovered. The transmitted power P_t is generally deduced from the wind power using the power coefficient C_p:

$$p_t = \tfrac{1}{2}C_\mathrm{p}\rho S V^3. \quad (3)$$

The power coefficient, C_p, is a non-linear function of the tip speed-ratio λ and the pitch angle β. The tip speed-ratio depends on the wind velocity and the rotation speed of the turbine:

$$\lambda = \frac{R\Omega}{V}. \quad (4)$$

Numerical approximations have been developed to calculate, for given values of λ and β, the power coefficient [18,19]. Here, the following approximation is used:

$$C_\mathrm{p}(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)\mathrm{e}^{-18.4/\lambda_i}, \quad (5)$$

with

$$\lambda_i = \frac{1}{[(1/\lambda - 0.02\beta) - (0.003/\beta^3 + 1)]}. \quad (6)$$

For the two other elements (the gearbox and the generator), one describes only their outputs that affect the quantity of energy produced by the wind turbine.

First, the output of the multiplier (gearbox) can be estimated from this formula [20,21]:

$$\eta_\mathrm{m} = 1 - \left[(1-\pi_\mathrm{m})\frac{(P_\mathrm{n}/P_\mathrm{r})+3}{4}\right], \quad (7)$$

with π_m is expressed as follows:

$$\pi_\mathrm{m} = 0.89P_\mathrm{n}^{0.012}. \quad (8)$$

The power to the exit of the multiplier is:

$$P_\mathrm{m} = \eta_\mathrm{m} P_\mathrm{t}. \quad (9)$$

Second, the nominal power of the generator is determined as follows:

$$P_\mathrm{g} = P_\mathrm{n}\pi_\mathrm{m}\pi_\mathrm{g}. \quad (10)$$

with π_g is calculated as follows:

$$\pi_\mathrm{g} = 0.87P_\mathrm{n}^{0.014}. \quad (11)$$

The output of the generator is given by [20,21]:

$$\eta_\mathrm{g} = 1 - \left[(1-\pi_\mathrm{g})\left(5\left(\frac{P_\mathrm{m}}{P_\mathrm{g}}\right)^2 + 1\right)\left(\frac{P_\mathrm{g}}{6P_\mathrm{m}}\right)\right]. \quad (12)$$

The global model of the calculation of the energy produced by a wind turbine is constructed while associating models of the three components presented above. Therefore, the recoverable wind power is determined as follows:

$$P_\mathrm{e} = C_\mathrm{e} P_\mathrm{v}, \quad (13)$$

with C_e is the efficiency coefficient of the wind turbine:

$$C_\mathrm{e} = C_\mathrm{p}\eta_\mathrm{m}\eta_\mathrm{g}. \quad (14)$$

In fact, the curve of progress of the wind turbine power according to the wind speed (Fig. 2) includes four zones:

- Zone «A», where the wind turbine doesn't produce a current: $P_\mathrm{e} = 0$;
- Zone «B», in which power is a function of the wind speed;
- Zone «C», where the rotation speed of the turbine is maintained constant by a regulation device: the power produced remains equal to P_n;
- Zone «D», in which the safety system of working wind turbine stops the rotation of the turbine and the transfer of the energy.

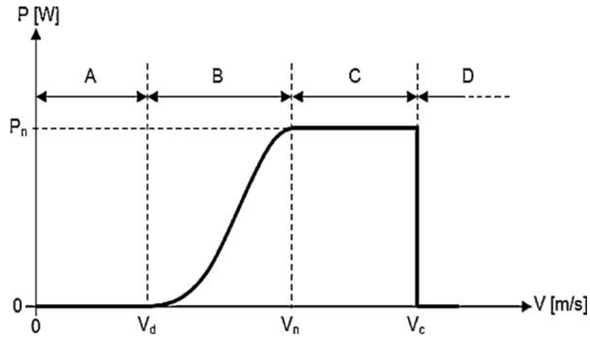

Fig. 2. Power output characteristic of a wind turbine.

Therefore the already presented models are applied only to determine the power produced by the wind turbine in the zone B.

In addition, it is certain that the height of the wind turbine installation presents a big effect on the produced energy; therefore the adjustment of the wind profile for the height must be taken in consideration. So, the wind speed to a determined height is expressed as follows:

$$\frac{V}{V_{\text{ref}}} = \left(\frac{Z}{Z_{\text{ref}}}\right)^{\alpha}. \tag{15}$$

Generally the value of α varies between 0.1 and 0.4 according to the nature of the installation site and its roughness.

3.2. Mathematical model of the unit of storage

Units of storage are introduced in the autonomous energizing systems to reply to the user's demand during periods of the unavailability of the renewable energy source. In this case, batteries are the units of storage used.

The capacity of batteries expressed in ampere-hour is defined as follows:

$$C_{\text{B}} = \frac{B_{\text{jp}} N_{\text{ja}}}{P_{\text{D}} R_{\text{T}}}, \tag{16}$$

where B_{jp} is the consumer's daily need in ampere-hour while taking account of losses (batteries present losses that can reach 10% of the daily consumption).

Everyday, the state of the unit of storage depends on the previous state of battery energy, the quantity of energy produced and the user's consumption.

During the charging process, when the total production of the wind turbine is superior to the demand of the consumer's loads, the quantity of the available energy in the unit of storage to the day t can be described by the following function [22]:

$$E_{\text{B}}(t) = E_{\text{B}}(t-1)(1-\sigma) + \left(E_{\text{e}}(t) - \frac{B_{\text{j}}(t)}{\eta_{\text{ond}}}\right)\eta_{\text{bat}}. \tag{17}$$

Moreover, when the loads demand is bigger than the energy produced, the unit of storage is in a discharge state. Therefore, the available energy in the unit of storage to this day t can be expressed as follows [9,10]:

$$E_{\text{B}}(t) = E_{\text{B}}(t-1)(1-\sigma) + \left(\frac{B_{\text{j}}(t)}{\eta_{\text{ond}}} - E_{\text{e}}(t)\right). \tag{18}$$

$E_{\text{B}}(t)$ and $E_{\text{B}}(t-1)$ are available energy in the unit of storage at day t and $t-1$ respectively. Batteries efficiency is in general equal to 1 during the discharge process and during the charging process, it is thereabouts 0.65–0.85 according to the intensity of the charging current. Also, the majority of the manufacturers esteem that for 6 months the self-discharge rate is 25% for a temperature of the storage of 20 °C, that is 0.14% per day [9,10].

At any time, the storage capacity is subject to the following constraints:

$$E_{\text{B}_{\text{min}}} \le E_{\text{B}}(t) \le E_{\text{B}_{\text{max}}}. \tag{19}$$

The nominal storage energy is often used for the determination of $E_{\text{B}_{\text{min}}}$ with:

$$E_{\text{B}_{\text{nom}}} = C_{\text{B}} V_{\text{B}}. \tag{20}$$

However, $E_{\text{B}_{\text{min}}}$ is calculated as follows:

$$E_{\text{B}_{\text{min}}} = (1 - P_{\text{D}}) E_{\text{B}_{\text{nom}}}. \tag{21}$$

4. Choice and optimization criteria

As mentioned above, the main objective of the present study is to determine a sizing tool able to find the optimal size of an autonomous wind system used to satisfy the requirements of a given load distribution assumed to be installed in a selected site. This tool is based on three main factors: the LEGP, the PSEP and the C_{kWh}.

It is noted that the total energy produced by the energizing system can or cannot satisfy the daily demand. Therefore, three different situations can occur:

- If the total produced energy is lower than the daily needs, then there would be a lack of energy produced: $E_{\text{e}} < B_{\text{j}}$,
- If the total produced energy is equal to the user's demand, there is neither excess nor lack: $E_{\text{e}} = B_{\text{j}}$,
- If the produced energy is greater than the demand, the produced power is in excess: $E_{\text{e}} > B_{\text{j}}$.

The used methodology can be summed up by the described below stages.

In the first case ($E_{\text{e}} < B_{\text{j}}$), the lack can be arranged by the energy stored in batteries. The available energy in batteries is calculated while using the expression (18).

But, if the energy quantity of the storage unit reaches its minimum level, $E_{\text{B}_{\text{min}}}$, the control system disconnects the consumer and the lack of energy to generate (LEG) can be expressed as follows [9–11]:

$$\text{LEG}(t) = B_{\text{j}}(t) - \left(E_{\text{e}}(t) + E_{\text{B}}(t-1) - E_{\text{B}_{\text{min}}}\right)\eta_{\text{ond}}. \tag{22}$$

In the third case ($E_{\text{e}} > B_{\text{j}}$), the surplus of energy is stored in batteries and the quantity of energy in the unit of storage is calculated while using Eq. (17) until the total capacity of the storage unit, $E_{\text{B}_{\text{max}}}$, is reached. At this moment, the control system stops the charging process. The remainder of produced power is not used.

Therefore, one can define a new surplus factor similar to the LEG. The surplus of the energy produced, is defined as follows:

$$\text{SEP}(t) = E_{\text{e}}(t) - \left(\frac{B_{\text{j}}(t)}{\eta_{\text{ond}}} + \left(\frac{E_{\text{B}_{\text{max}}} - E_{\text{B}}(t-1)}{\eta_{\text{bat}}}\right)\right). \tag{23}$$

From these two factors (LEG and SEP) one can determine two main criteria of choice for the autonomous wind system that are the LEGP and the PSEP.

During a period considered T, the LEGP can be defined as being the report between the sum of the lack and the consumer's total need. It can be given by the following expression:

$$\text{LEGP} = \frac{\sum_{t=1}^{T} \text{LEG}(t)}{\sum_{t=1}^{T} \text{B}_{\text{j}}(t)}. \tag{24}$$

where T represents the period of survey (in our case, $T = 1$ year).

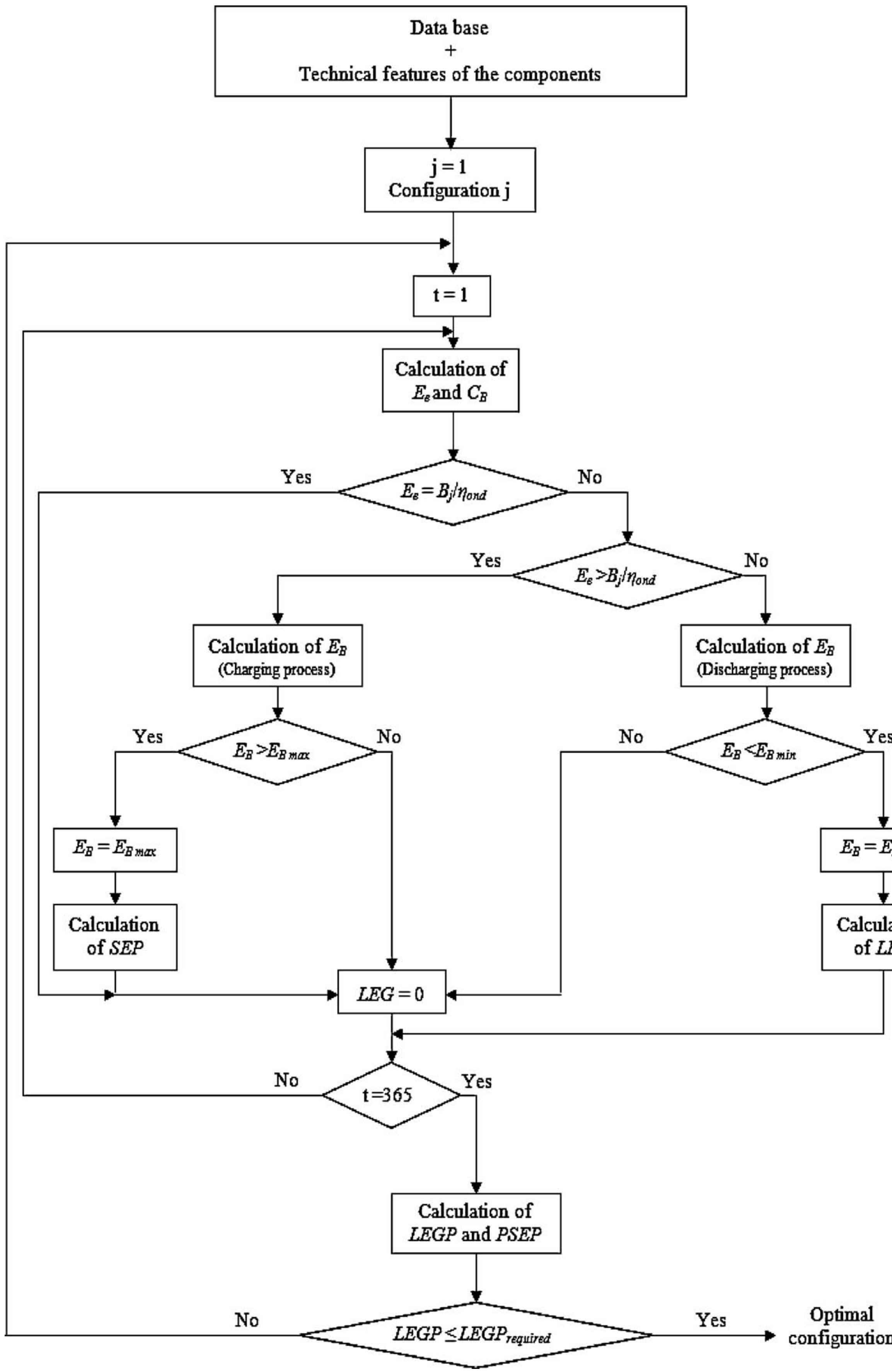

Fig. 3. Algorithm of the wind system operation simulation.

In the same way, the PSEP is defined as being the report between the sum of the surplus of the energy produced and the consumer's total need as:

$$\mathrm{PSEP} = \frac{\sum_{t=1}^{T} \mathrm{SEP}(t)}{\sum_{t=1}^{T} B_{\mathrm{j}}(t)}. \tag{25}$$

From the described above situations, an algorithm of calculation is developed. This algorithm is illustrated in Fig. 3.

The algorithm input data are composed of the wind speed values, the required LEGP, the daily needs during all year round and features of the system components.

Using the proposed algorithm and for a required value of LEGP and a very definite period, a lot of configurations can, technically, satisfy the consumer's energizing demand.

The optimum configuration of a wind system can make the best compromise between the two considered objectives: the system power reliability and system cost. The economical approach, according to the concept of actualized total cost of system, is developed to be the best target of system cost analysis in this study.

Therefore, from an economic view point, qualification criteria of a wind project are C_{ta} and E_{ea}. These two criteria allow us to calculate the cost of the kilowatt-hour produced by the project:

$$C_{\mathrm{kWh}} = \frac{C_{\mathrm{ta}}}{E_{\mathrm{ea}}}. \tag{26}$$

The configuration presenting the lowest C_{kWh} is taken as the optimal solution to the configurations that guarantee the LEGP required.

The actualized total cost, C_{ta}, is calculated by the following relation [20,21]:

$$C_{\mathrm{ta}} = aC_{\mathrm{ii}} + C_{\mathrm{m}} + C_{\mathrm{r}}, \tag{27}$$

with a as the actualization factor defined by:

$$a = \frac{r}{1-(1+r)^{-n}}, \tag{28}$$

n is the system lifetime and r is the actualization rate; r is considered like 8% for this type of system.

The initial cost of investment of the system includes prices of components (wind generator including tower, batteries, the regulator, the inverter, etc.), the cost of the civil work and the cost of the installation and the connections cables. In this study, the costs of civil work and installation are estimated to 20% of the price of the wind turbine. Also, the system lifetime is supposed equal to 25 years. It is the wind turbine lifetime while the lifetime of batteries is 5–10 years. Therefore, batteries should be replaced several times during the system life.

The replacement cost mainly depends on the replacement of some parts of the installation. Since the wind generator has the life of the system, its replacement cost can be considered as zero, while the batteries must be replaced. The present value of replacement cost can be determined as follows [8,9]:

$$C_r = C_{r_1} f_r, \tag{29}$$

where C_{r_1} is the cost of a replacement and f_r can be expressed as follows:

$$f_r = \frac{r}{(1+r)^{nb}-1}. \tag{30}$$

The system maintenance cost, which has taken the f_{m} into account, is given as [8]:

$$C_{\mathrm{m}}(\eta) = C_{\mathrm{m}}(1)(1+f_{\mathrm{m}}). \tag{31}$$

$C_{\mathrm{m}}(1)$ is the maintenance cost for one year. For this study, it is estimated to 2.5% of the cost of the wind generator. Generally the value of f_{m} is equal to 1.5%.

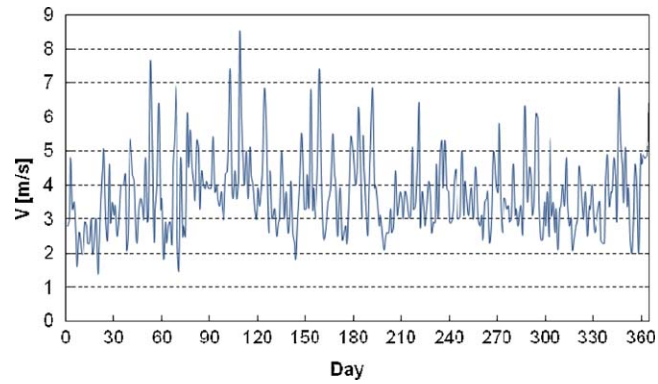

Fig. 4. Daily wind speed at the region of Sfax for a height of 12 m.

5. A case study of the optimal sizing tool

As previously mentioned, the study objective is to analyze, from the technical-economic point of view, an autonomous wind system. The mentioned above method will be used for this analysis. While exploiting the algorithm, a FORTRAN simulation code has been elaborated.

As a case study, this method is applied to analyze a project which is designed to guarantee the energizing demands of a domestic house located in Sfax, Tunisia. Based on 1 year of meteorological data at this station, the daily evolution of the wind speed for the year 2007 is presented in Fig. 4.

According to the project requirements and technical considerations, a constant power consumption of 3500 W is chosen to be the system load requirement. Besides, one could have determined that for a modern house, the daily needs in energy are estimated to be 5 kWh/day.

Moreover, the determination of the storage unit capacity is a very important phase in the autonomous system sizing. Therefore, formula (16) is used to calculate this size with:

- B_{j} = 5 kWh/day therefore B_{jp} = 105 Ah/day,
- N_{ja} = 3 days (it is a middle value whose choice will be justified subsequently),
- P_{D} = 0.8 (maximal discharge to 80%),
- R_{T} = 0.95 (this coefficient essentially depends on the installation site and the meteorological conditions of the site).

Therefore the necessary capacity for our installation is: C_{B} = 415 Ah.

NOTE: We have chosen a batteries voltage equals to 48 V because the system power is relatively important and to facilitate the choice of the other system components such as the regulator of charging/discharging and the DC/AC converter.

Using these data in the simulation algorithm, the different technical feature has been done for some system combinations. A comparative analysis of the different system components combinations has been achieved to lead to the best choice of the optimal autonomous system.

The technical and economic characteristics of the main system components are presented in Tables 1 and 2.

6. Simulation results and discussion

The relationships between system reliabilities and system configurations are studied, as well as the relationships between the cost of kilowatt-hour produced and system configurations. The optimal configurations of the system are given accordingly for different desired reliability requirements.

Table 1
Features of the studied wind turbines.

Model	P_n (W)	Ø (m)	V_d (m/s)	V_n (m/s)	V_c (m/s)	Voltage (V)	Price (€)
C1: Cyclone 1 kW	1000	2.7	2.5	9	15	48 VDC	1445
sky: Skystream 3.7	1800	3.72	2.5	9	25	240 VAC	4308
C3: Cyclone 3 kW	3000	4.5	2.5	10	15	120 VDC	3760

Table 2
Properties of the used batteries.

Model	Nominal capacity (Ah)	Voltage (V)	P_D	Price (€)
STECO	154	12	0,8	276.5
Banner 250	250	12	0,8	459
Surette	503	12	0,8	775

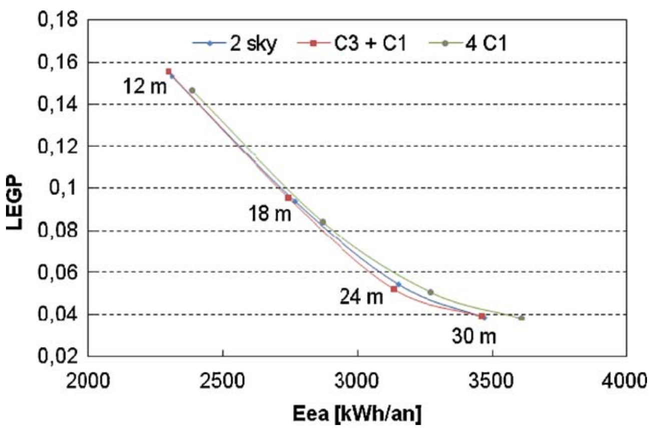

Fig. 5. Variation of the LEGP according to E_{ea}.

6.1. System configurations reliabilities

In this part, characteristic of the different system components are determined while respecting the two choice criteria LEGP and PSEP.

The comparison of some system configurations, through the change of the wind turbine, gave the results presented in Figs. 5 and 6. These figures represent the relation between the change of the wind generator and the variation of the two criteria LEGP and PSEP.

Curves (Fig. 5) represent the LEGP evolution according to the annual wind energy produced E_{ea} for different combinations of wind turbine and for four heights of reference (12, 18, 24 and 30 m).

We notice that all combinations produce an important annual energy. This energy can satisfy the demands of the domestic house. However, the LEGP coefficient is relatively important. This coefficient didn't attain the zero value in spite of the height increase.

Curves (Fig. 6) represent the evolution of the two criteria LEGP and PSEP while varying the height of the installation for the different system configurations. We perceive that there is a similarity of the variation in the different cases. In the same way, the evolution of these two criteria is harmonic: while increasing the height of the installation of the wind turbine, the growth of the PSEP is followed by a reduction of the LEGP. It is evident because the quantity of the energy produced by the wind generator increases with the height.

The comparison of these different system configurations, according to energizing criteria LEGP and PSEP, prove that these different wind turbines can be exploited in our installation because the consumer's demand has been covered in spite of some deficiencies revealed at the LEGP level.

Therefore, it remains to confirm these results through the third criteria of choice: the economic criteria C_{kWh}.

6.2. System configurations cost

The different configurations meeting desired LEGP requirements are obtained from the simulation results. After the technical process, the cost of energy (C_{kWh}) is utilized as the economic factor.

The simulation results are demonstrated and the relationships between the C_{kWh} and system configurations are analyzed. The minimum cost of the kilowatt-hour produced for different LEGP is calculated by the proposed optimal sizing method.

In an attempt to clarify the impact of the LEGP on the C_{kWh}, Fig. 7 shows the simulation results related to the variation of the C_{kWh} with the LEGP for the considered system configurations. It is clear that, for the three system configurations, C_{kWh} values decrease when those of the LEGP decrease.

This result is obvious because the increase of the installation height is followed by an increase of the energy produced. Therefore, the C_{kWh} decreases, in the same way, values of the LEGP cut down.

As shown in Fig. 8, the curves of the C_{kWh} for the configurations meeting the desired LEGP are plotted for different installation heights.

We note that there is a resemblance in the decreasing variation of the C_{kWh} for the three cases of installation. However, two config-

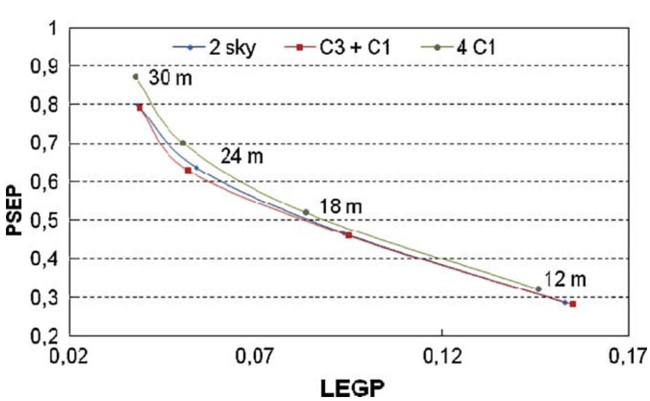

Fig. 6. LEGP and PSEP evolution for different system configurations.

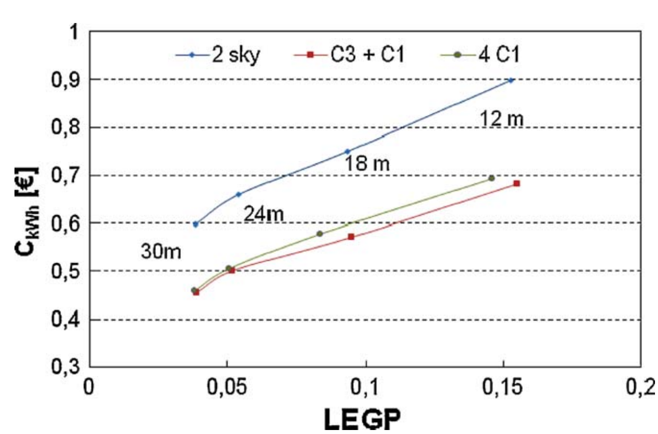

Fig. 7. The impact of the LEGP on the C_{kWh} of wind system.

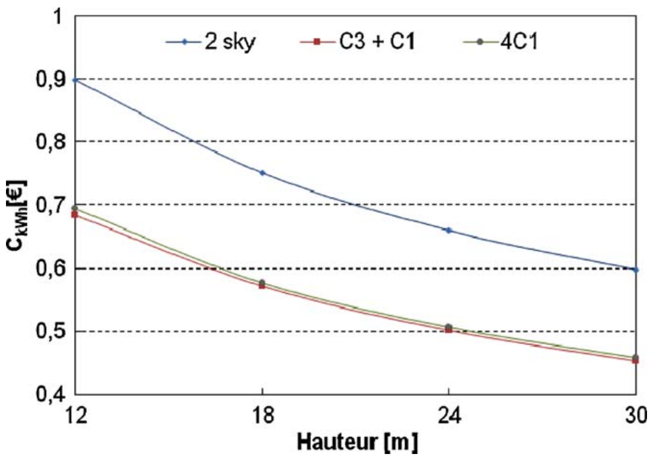

Fig. 8. Influence of the installation height on the cost of the kilowatt-hour produced.

urations present some near and better results than the third one. Therefore, these two configurations can be considered as being the optimal configurations of the system.

The choice of the height of the installation is decided by the consumer, through which the specification of the final optimal system is achievable.

6.3. Explanation of the N_{ja} value choice

After having determined the optimal features of the system, we try to justify the choice of the number of autonomy days because it is a very important factor that can affect extensively the system characteristics.

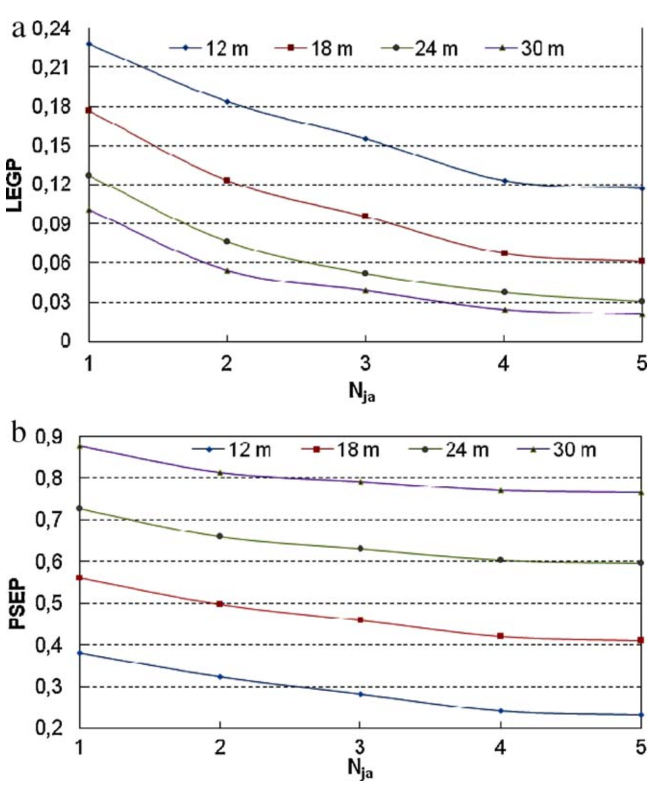

Fig. 9. Influence of the number of autonomy day on the choice criteria: (a) on LEGP, (b) on PSEP.

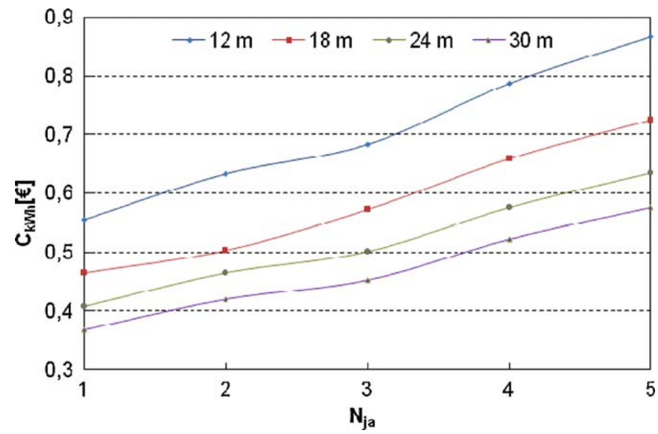

Fig. 10. Influence of the number of autonomy day on C_{kWh}.

Therefore, the impact of this factor on the different choice criteria (LEGP, PSEP, C_{kWh}) is evaluated. Simulation results are represented in Figs. 9a, b and 10.

We notice that these criteria vary with a relatively remarkable way according to the increase of the N_{ja}. Besides, this influence is more important on the LEGP and C_{kWh} criteria than on the PSEP.

The two energizing criteria (LEGP and PSEP) decrease if one increases the number of autonomy days (N_{ja}): the reduction of the LEGP is considerable therefore the increase of the value of the N_{ja} is in favor of this criteria.

However, the C_{kWh} increases significantly according to the increase of the N_{ja}, especially for the least elevated heights.

The satisfaction, with an optimal manner, of the consumer's energizing requirements is our main objective, so it is necessary to always think about the compromise cost/energy consumed to do the best choices. Then, from these three figures, we note that the best solution is to choose a middle value for the number of autonomy days: as a result the N_{ja} chosen value is equal to 3 days.

7. Conclusion

Power supply reliability under varying weather conditions and the corresponding system cost are the two major concerns in designing wind systems. In order to utilize wind energy efficiently and economically, an optimum sizing method is developed in this paper based on a simulation algorithm, which is able to attain the global optimum result with a relative simplicity compared to the conventional optimization methods.

The main objective of the present method is to estimate the optimum size of such system able to accomplish the load energy requirements with minimum cost and high reliability at considered sites and to analyze the impact of different parameters on the system size.

In this setting, the following steps have been used:

- Main subsystem modeling: the energizing models and the mathematical equations have been used.
- Choice criteria determination (LEGP, PSEP and C_{kWh}): these criteria serve to the selection of the optimal system configuration properties.

These models and these criteria have been exploited to develop a calculation algorithm.

The proposed method has been applied to analyze a wind system to supply power for a domestic house located in Sfax, Tunisia. This system is simulated by running the resolution algorithm. The

relationships of system reliabilities and cost with system configurations are also analyzed. The optimal configurations of the wind system are obtained in terms of different desired system reliability requirements and the cost of the kilowatt-hour produced.

In spite of the increase of the wind generators size, the value of the LEGP didn't attain zero. Therefore, to satisfy the user's energizing needs in case of lack, it is necessary to consider a complementary system that can be a photovoltaic system, a diesel group or other.

This sizing method can be applied to any locations taking account of the meteorological data and the load profile of any installation. Also, it allows us to determine the optimal system configuration allowing the consumers to decide what system configuration will be installed to satisfy the energy load requirements with the lowest cost.

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